SOILWATER CONSULTANTS

# MUMMALOO DEPOSIT GEOCHEMICAL CHARACTERISATION

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**LIMITATIONS**

The sole purpose of this report and the associated services performed by Soil Water Consultants (SWC) was to undertake geochemical characterisation on the Mummaloo deposit. This work was conducted in accordance with the Scope of Work presented to EnviroWorks (‘the Client’).

SWC performed the services in a manner consistent with the normal level of care and expertise exercised by members of the earth sciences profession. Subject to the Scope of Work, the geochemical characterisation was confined solely to the Mummaloo deposit. No extrapolation of the results and recommendations reported in this study should be made to areas external to this project area. In preparing this study, SWC has relied on published soil reports from various soil researchers and information provided by the Client. All information is presumed accurate and SWC has not attempted to verify the accuracy or completeness of such information. While normal assessments of data reliability have been made, SWC assumes no responsibility or liability for errors in this information. All conclusions and recommendations are the professional opinions of SWC personnel.

SWC is not engaged in reporting for the purpose of advertising, sales, promoting or endorsement of any client interests. No warranties, expressed or implied, are made with respect to the data reported or to the findings, observations and conclusions expressed in this report. All data, findings, observations and conclusions are based solely upon site conditions at the time of the investigation and information provided by the Client.

This report has been prepared on behalf of and for the exclusive use of the Client, its representatives and advisors. SWC accepts no liability or responsibility for the use of this report by any third party

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# 1. INTRODUCTION

Soil Water Consultants (SWC) were engaged by Enviroworks Consulting to conduct a geochemical characterisation of the ore, waste rock and overburden at the proposed Mummaloo deposit to confirm the presence or absence of potential acid forming (PAF) materials and to assess the potential for metalliferous drainage (MD) to occur following disturbance of these materials.

## 1.1 STUDY OBJECTIVES

The specific objectives of this work were to:

- Assess the current baseline geochemical conditions existing within the proposed Mummaloo Deposit.
- Undertake an Acid Base Account (ABA) to identify any environmental risks associated with disturbance of any ARD materials, if present.
- Identify any risk of MD following disturbance of the mined materials.
- Suggest management strategies for the handling and utilisation of the waste rock materials during mining and rehabilitation, if required.

## 1.2 SCOPE OF WORK

The scope of work (SOW) completed by SWC for this project included:

- Review of existing assay drill data for this deposit.
- Identification of representative drill holes providing sufficient spatial coverage of deposit.
- Undertake and coordinate the initial laboratory screen analysis.
- Selection of samples for additional detailed laboratory analysis to confirm their Acid Rock Drainage (ARD) and Metalliferous Drainage (MD) status.
- Review of laboratory results and preparation of this report.

## 2. METHODOLGY

### 2.1 STUDY LOCATION

The Mummaloo deposit is located approximately half-way between Wubin and Paynes Find, along the Great Northern Highway, and represents a shallow ore body up to 6 m deep.

### 2.2 REVIEW OF THE EXISTING GEOLOGICAL DRILLING & ASSAY DATA

A total of 191 holes have been drilled as part of the exploration of the Mummaloo deposit. Holes were drilled to depths between 0 and 102 m, with samples collected at 2 m vertical intervals over the entire length, resulting in a total of 1167 samples (soils and pulps) that were assayed for total iron (Fe), silica (Si), aluminium (Al), phosphorous (P), titanium (Ti), magnesium (Mg), manganese (Mn), calcium (Ca), potassium (K) and total sulfur (S), arsenic (As), cobalt (Co), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb), selenium (Se), vanadium (V) and zinc (Zn). The desktop assessment involved reviewing of the data and identifying areas of potential PAF.

### 2.3 LABORATORY ANALYSIS

A total of 23 samples (soils and pulps) were provided by Enviroworks that were selected from the 191 drill holes. These samples were taken from a total of 7 drill holes at varying depths. The samples were subjected to laboratory screening to identify those which were potential PAF and therefore requiring detailed ARD assessment.

All samples collected were assessed for pH and $pH_{FOX}$, according to the following methods:

- pH – 1:5 soil/water ratio. This parameter measures the existing acidity of the materials and determines if previous oxidation of the sulfides has occurred and the potential buffering capacity of the materials.
- $pH_{FOX}$ – pH of the materials following the addition of 30 % hydrogen peroxide to rapidly oxidise any sulfides present. The method is outline in Stone *et al*. (1998)

From the results of the pH, $pH_{FOX}$ and EC and the review of the geological drilling data, a total of 12 samples were further selected for detailed ARD and geochemical test work consisting of:

- Chromium Reducible Sulfur ($S_{CR}$)
- Static Net Acid Generation (NAG)
- Acid Neutralising Capacity (ANC)
- Total Inorganic Carbon (TIC)
- Multi-element composition (As, Ba, Cd, Co, Cr, Mn, Ni, Pb and Zn)

All external analyses were carried out by ALS (NATA accredited).

# 3. RESULTS

## 3.1 PH AND PH$_{FOX}$

The results of the pH and pH$_{FOX}$ for the 23 samples are presented in Table 1 with Figures 2 and 3 showing the location of the samples taken for pH and pH$_{FOX}$ in the corresponding depth profiles of the 7 drill holes.

The field pH of all the samples ranged from 4.33 to 8.48. Around 50 % of the samples were alkaline (pH >7) and the remainder were moderately acidic (pH 5 – 7) with 3 found to be strongly acidic (pH 4 – 5). The effect on pH of addition of peroxide (pH$_{FOX}$) was minimal with only one sample exhibiting a decrease in pH of greater than one unit though the final pH was greater than pH 7. The similarity between the pH and pH$_{FOX}$ values (i.e. pH-pH$_{FOX}$ <1 pH unit) indicate that if the sulfides were originally present they have completely oxidised. Where pH$_{FOX}$ was greater than the initial pH, this indicates the presence of carbonates and acid neutralising potential in the material.

Figure 1 shows the results of linear regression analysis of the pH$_{FOX}$ and the % S. The results show that there is no relationship between the two parameters, which supports the findings of the desktop assessment, that the materials in the Mummaloo deposit are unlikely to be PAF.

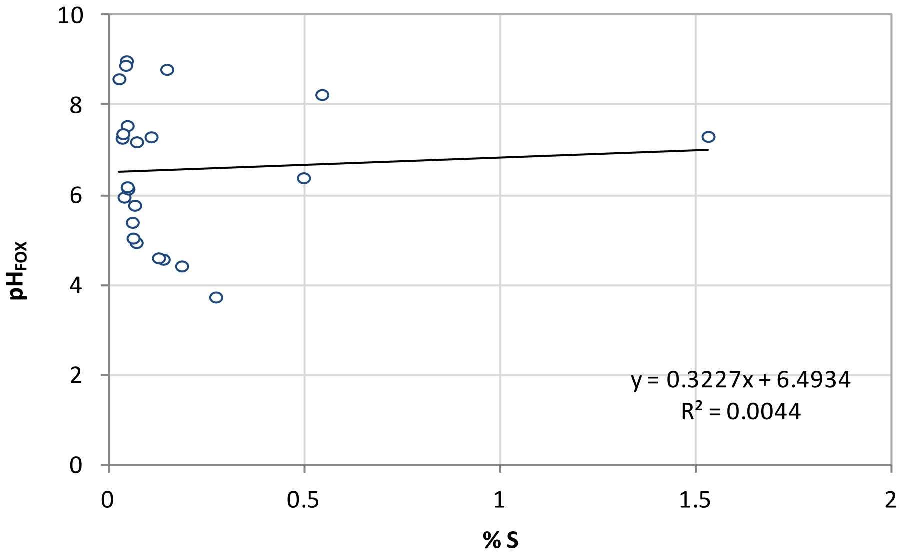
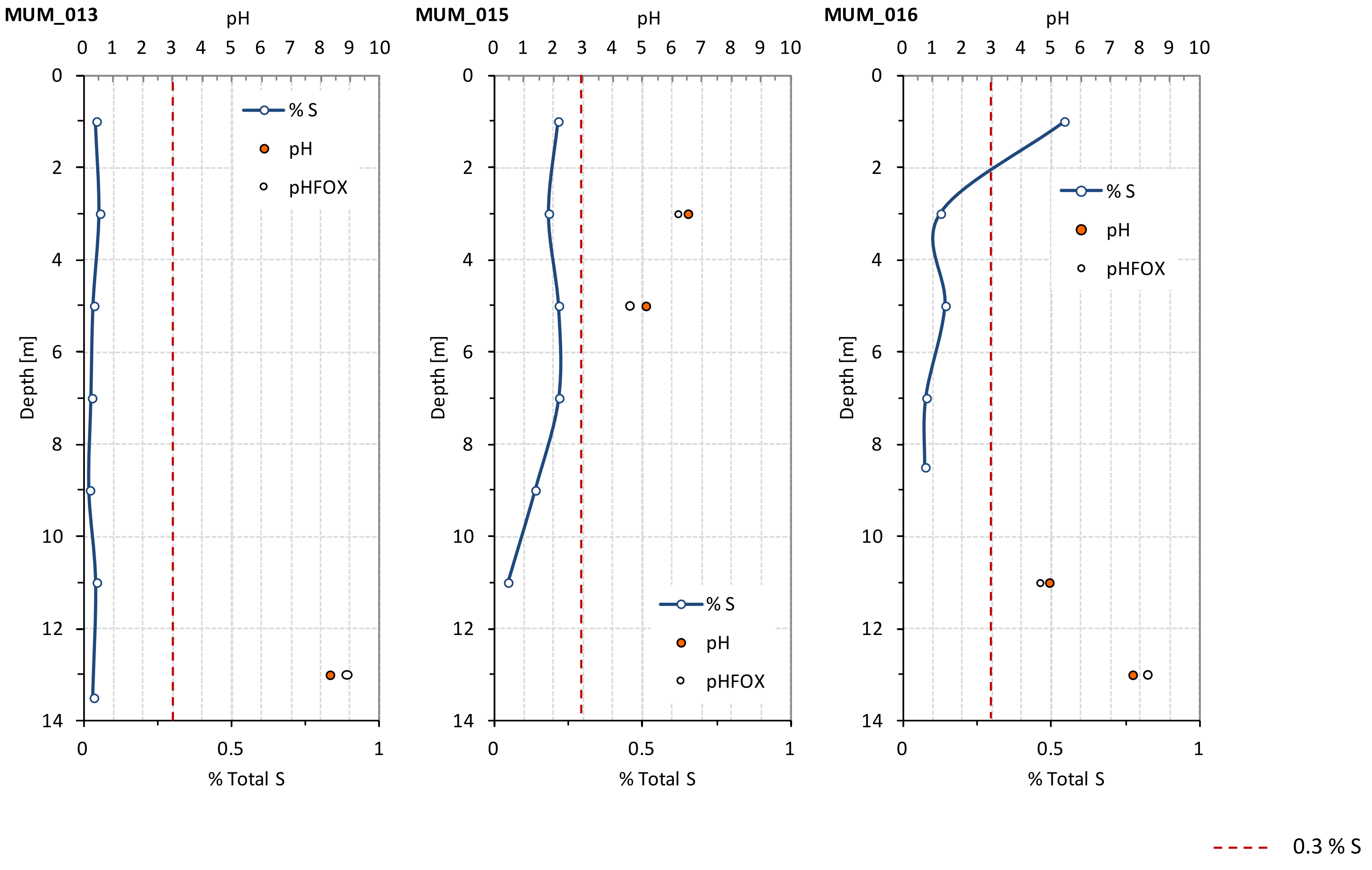



Figure 1: Linear regression plot for pH$_{FOX}$ and %

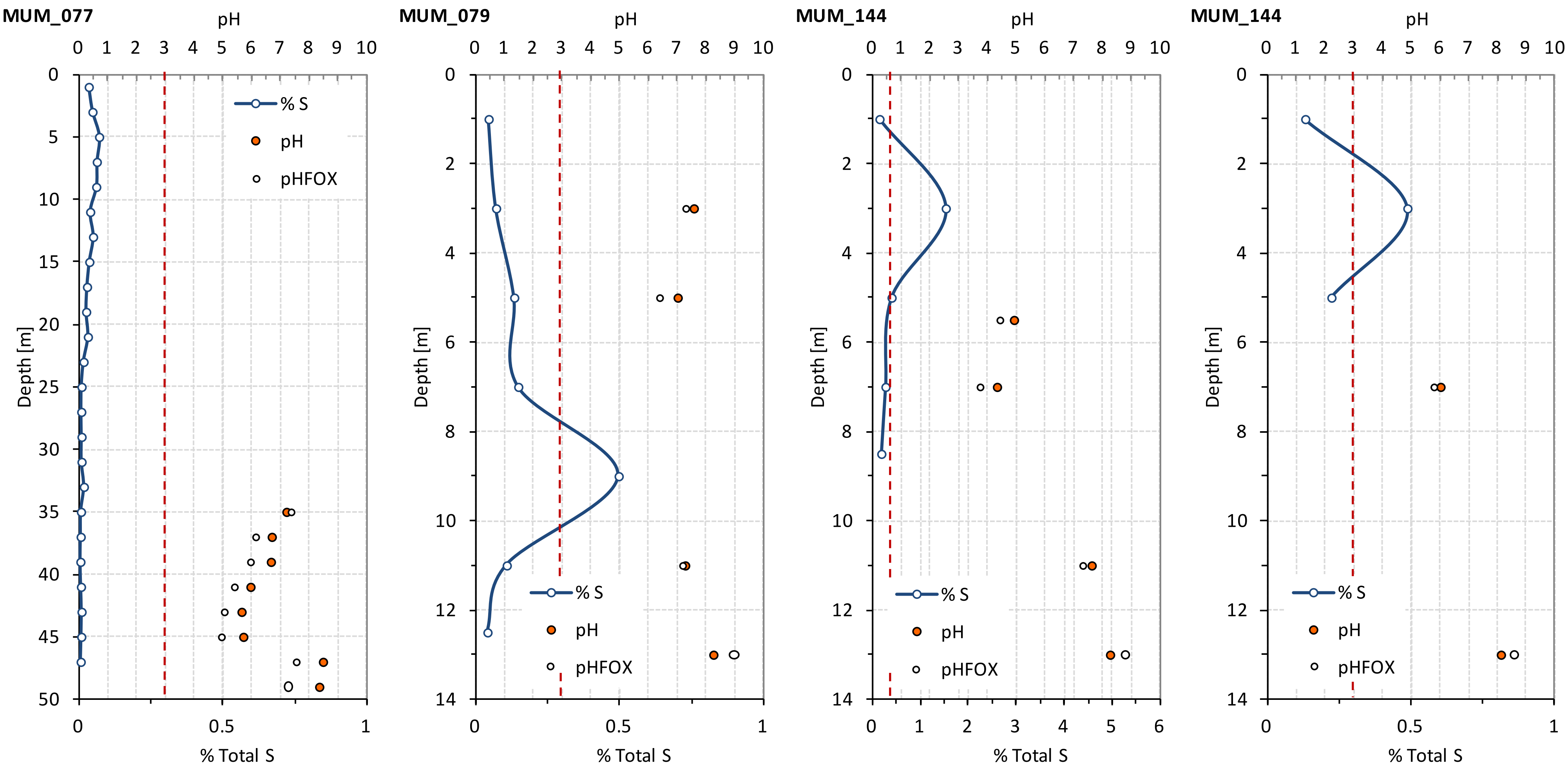
Table 1: Results of laboratory screen test work on selected drill hole samples

| Drill hole number | Depth (m) | pH | pH$_{FOX}$ | pH-PH$_{FOX}$ |
|---|---|---|---|---|
| MUM_077 | 0-2 | 8.35 | 7.27 | 1.08 |
| MUM_077 | 2-4 | 8.48 | 7.55 | 0.93 |
| MUM_077 | 4-6 | 5.71 | 4.95 | 0.76 |
| MUM_077 | 6-8 | 5.65 | 5.05 | 0.6 |
| MUM_077 | 8-10 | 5.96 | 5.4 | 0.56 |
| MUM_077 | 10-12 | 6.67 | 5.96 | 0.71 |
| MUM_077 | 12-14 | 6.7 | 6.14 | 0.56 |

| | | | | |
|---|---|---|---|---|
| MUM_077 | 14-16 | 7.21 | 7.37 | -0.16 |
| MUM_079 | 0-2 | 8.26 | 8.99 | -0.73 |
| MUM_079 | 2-4 | 7.28 | 7.19 | 0.09 |
| MUM_079 | 8-10 | 7.02 | 6.39 | 0.63 |
| MUM_079 | 10-12 | 7.58 | 7.3 | 0.28 |
| MUM_015 | 8-10 | 5.11 | 4.58 | 0.53 |
| MUM_015 | 10-12 | 6.53 | 6.19 | 0.34 |
| MUM_016 | 0-2 | 7.74 | 8.24 | -0.5 |
| MUM_016 | 2-4 | 4.93 | 4.61 | 0.32 |
| MUM_144 | 0-2 | 8.26 | 8.8 | -0.54 |
| MUM_144 | 2-4 | 7.62 | 7.31 | 0.31 |
| MUM_144 | 6-8 | 4.33 | 3.74 | 0.59 |
| MUM_144 | 8-9 | 4.92 | 4.43 | 0.49 |
| MUM_146 | 0-2 | 8.11 | 8.59 | -0.48 |
| MUM_146 | 6-8 | 6.01 | 5.78 | 0.23 |
| MUM_013 | 0-2 | 8.3 | 8.89 | -0.59 |




| PN | PN0266 | | EnviroWorks Consulting<br>MUMMALOO DEPOSIT GEOCHEMICAL CHARACTERISATION<br>**% S, pH AND $pH_{FOX}$ CONTENT OF SELECTED DRILL HOLES** | **Figure 2** |
|---|---|---|---|---|
| Prep by | HC | 23/07/12 | | soilwater GROUP |
| Rev'd by | ASP | 23/07/12 | | |
| Revision No. | 0 | | | |




| PN | PN0266 | | EnviroWorks Consulting<br>MUMMALOO DEPOSIT GEOCHEMICAL CHARACTERISATION<br>**% S, pH AND pH$_{FOX}$ CONTENT OF SELECTED DRILL HOLES CONT.** | **Figure 3** |
|---|---|---|---|---|
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| Revision No. | 0 | | | |

### 3.2 SULFUR SPECIATION

#### TOTAL SULFUR

A summary of the findings from the desktop study are shown in Table 2 and the results of the detailed ARD analyses for the 12 representative samples are presented in Table 3.

This desktop study found that the % S content of the materials in the deposit ranged from 0.003 to 5.9 % with an average total S content of 0.18 %. The critical level of total S content is 0.3 % (AMIRA, 2002) and an assessment of the samples found that a total of 1040 of them were below the 0.3 % . The elevated total S contents in the surface 30 – 40 m of the profile is likely due to the presence of relatively soluble basic sulfates (i.e. gypsum) or acidic sulfates, such as hydrated Fe- and/or Al- sulfates, which have the potential to release relatively small quantities of acidity (H+) during dissolution (Price, 2009).

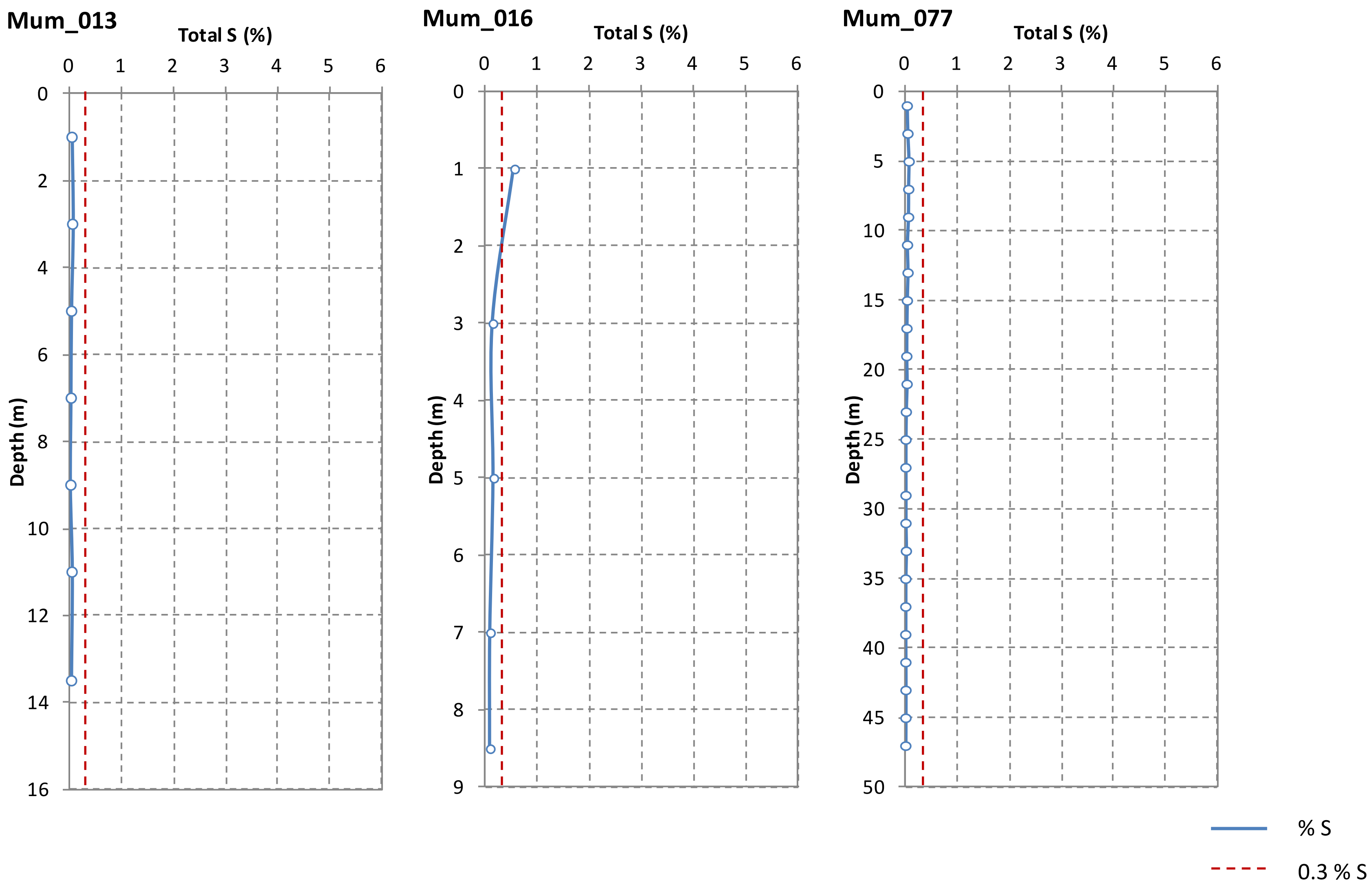
For 21 of the drill holes that contained samples that exceed the 0.3 % total S threshold the depth profile of S content was plotted and the results are presented in Figures 4 – 10. These figures show that in all cases the high total S content is expressed as a peak within the top 6 m of the profiles. The material at this depth is highly weathered and it likely that the elevated total S is the result of previous oxidation of sulphidic materials and the subsequent release of $SO_4$. As such the high % S content of these materials is not indicative of the presence of PAF.

Table 2: Summary of the assay data on 191 drill holes sampled at Mummaloo.

| Analyte | Minimum (%) | Maximum (%) | Mean (%) |
|---|---|---|---|
| Fe | 0.010 | 51.4 | 22.26 |
| $Al_2O_3$ | 0.050 | 37.1 | 15.57 |
| CaO | 0.003 | 15.0 | 1.29 |
| $K_2O$ | 0.005 | 8.4 | 0.33 |
| MgO | 0.005 | 30.5 | 2.27 |
| MnO | 0.003 | 1.6 | 0.06 |
| $Na_2O$ | 0.005 | 7.0 | 0.43 |
| P | 0.003 | 0.2 | 0.02 |
| S | 0.003 | 5.9 | 0.18 |

#### CHROMIUM REDUCIBLE SULFUR ($S_{CR}$)

The results for the chromium reducible sulfur for all samples were below 0.007 % (data not shown) which is significantly less than the DEC (2009) 0.03 % criteria level. Corresponding maximum potential acidity (MPA) is also low, with the majority of the samples having an MPA of 0.153 kg $H_2SO_4$/t or less (Table 3). This supports the results from the desktop study and the laboratory screening which suggest that the elevated % S contents found for some drill hole samples were not due to sulfides and can be attributed to $SO_4$-S species.

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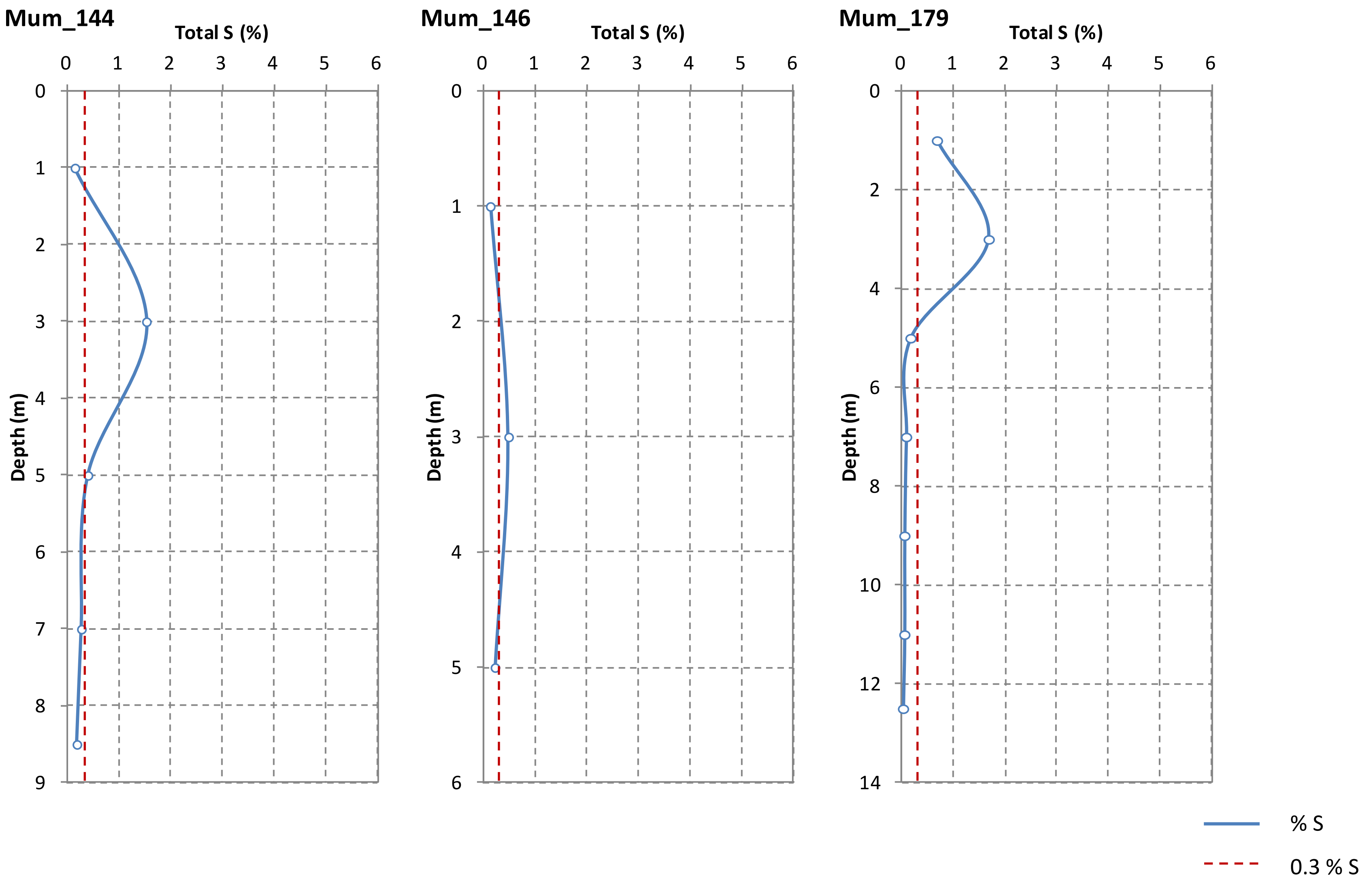
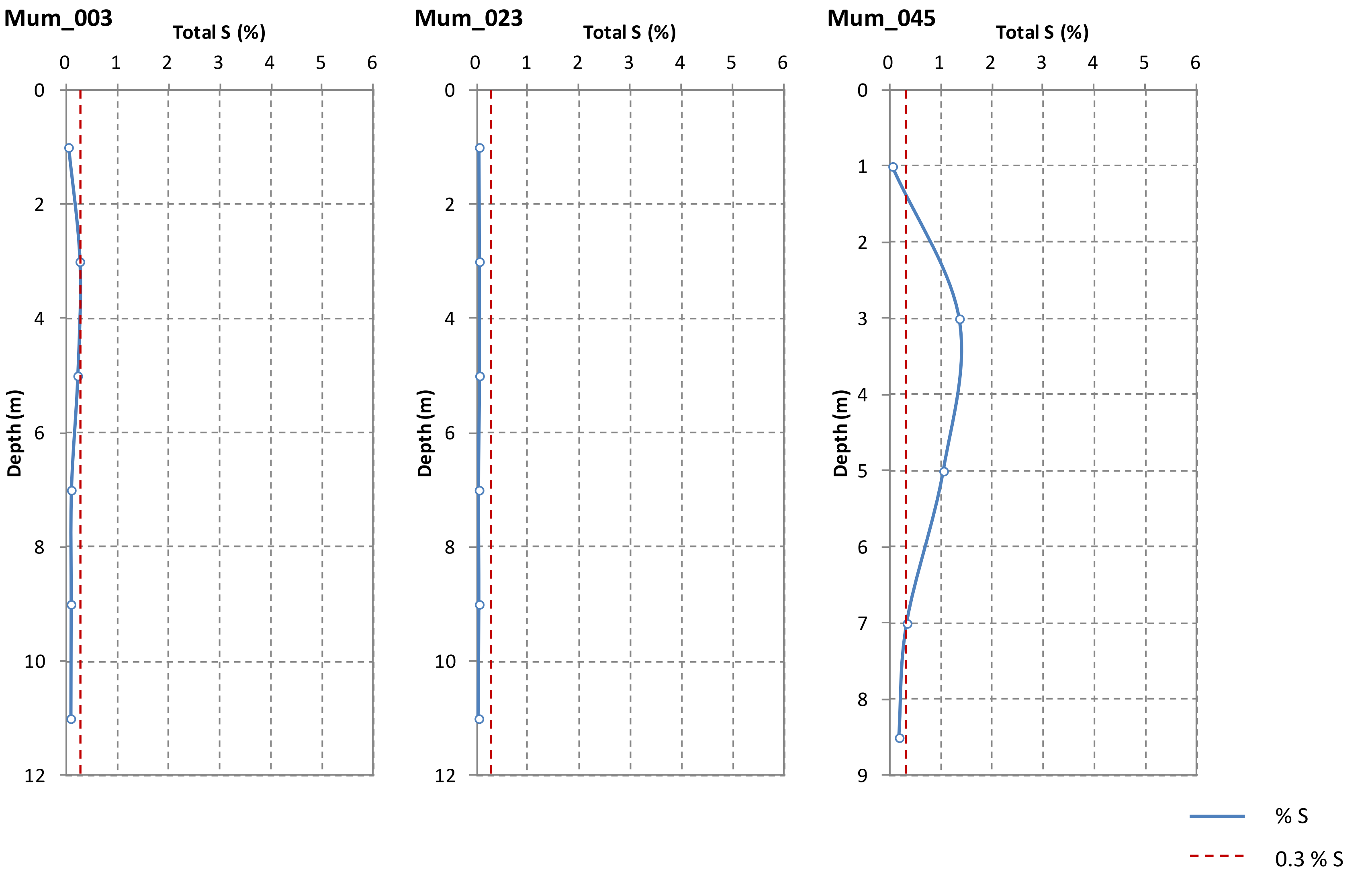
**% S CONTENT OF SELECTED DRILL HOLES**

**Figure 4**

soilwater GROUP




| PN | PN0266 | | EnviroWorks Consulting<br>MUMMALOO DEPOSIT GEOCHEMICAL CHARACTERISATION<br>**% S CONTENT OF SELECTED DRILL HOLES CONT.** | **Figure 5** |
|---|---|---|---|---|
| Prep by | HC | 23/07/12 | | |
| Rev'd by | ASP | 23/07/12 | | |
| Revision No. | 0 | | | |




| PN | PN0266 | | EnviroWorks Consulting<br>MUMMALOO DEPOSIT GEOCHEMICAL CHARACTERISATION<br>**% S CONTENT OF SELECTED DRILL HOLES CONT.** | **Figure 6** |
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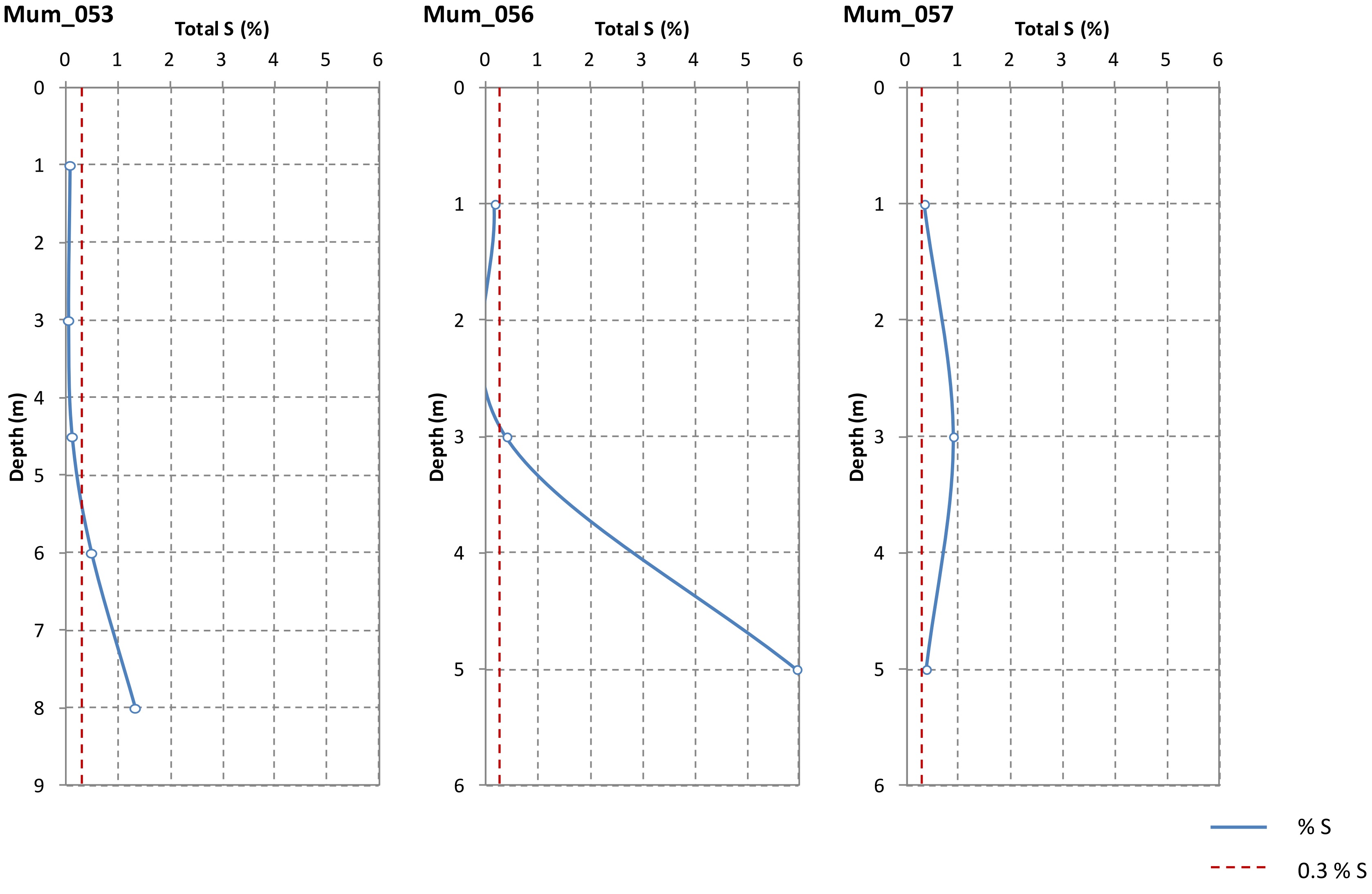


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**% S CONTENT OF SELECTED DRILL HOLES CONT.**

**Figure 7**

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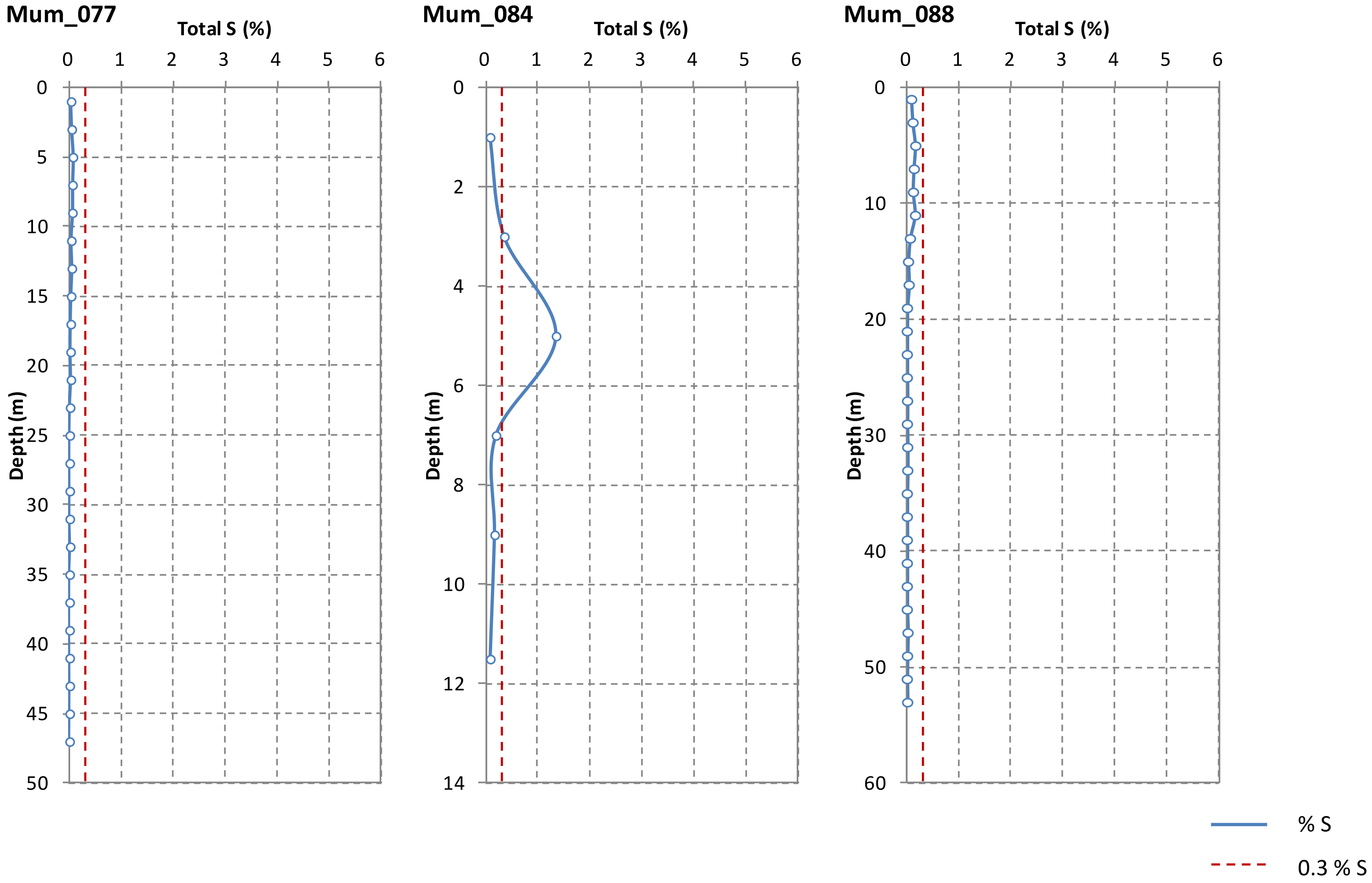


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MUMMALOO DEPOSIT GEOCHEMICAL CHARACTERISATION

**% S CONTENT OF SELECTED DRILL HOLES CONT.**

**Figure 8**

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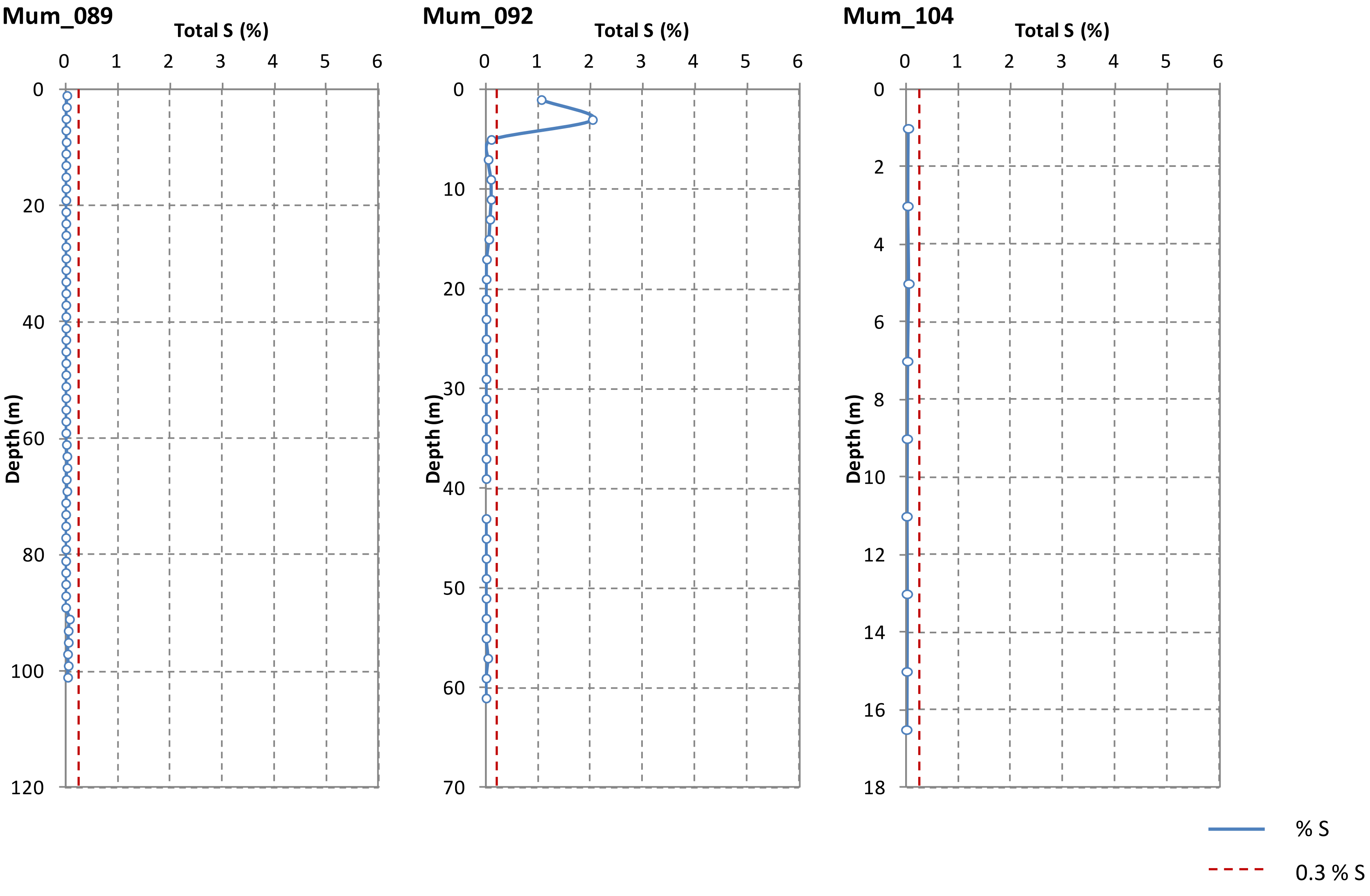


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| PN | PN0266 | | EnviroWorks Consulting<br>MUMMALOO DEPOSIT GEOCHEMICAL CHARACTERISATION<br>**% S CONTENT OF SELECTED DRILL HOLES CONT.** | **Figure 9** |
| Prep by | HC | 23/07/12 | | soilwater GROUP |
| Rev'd by | ASP | 23/07/12 | | |
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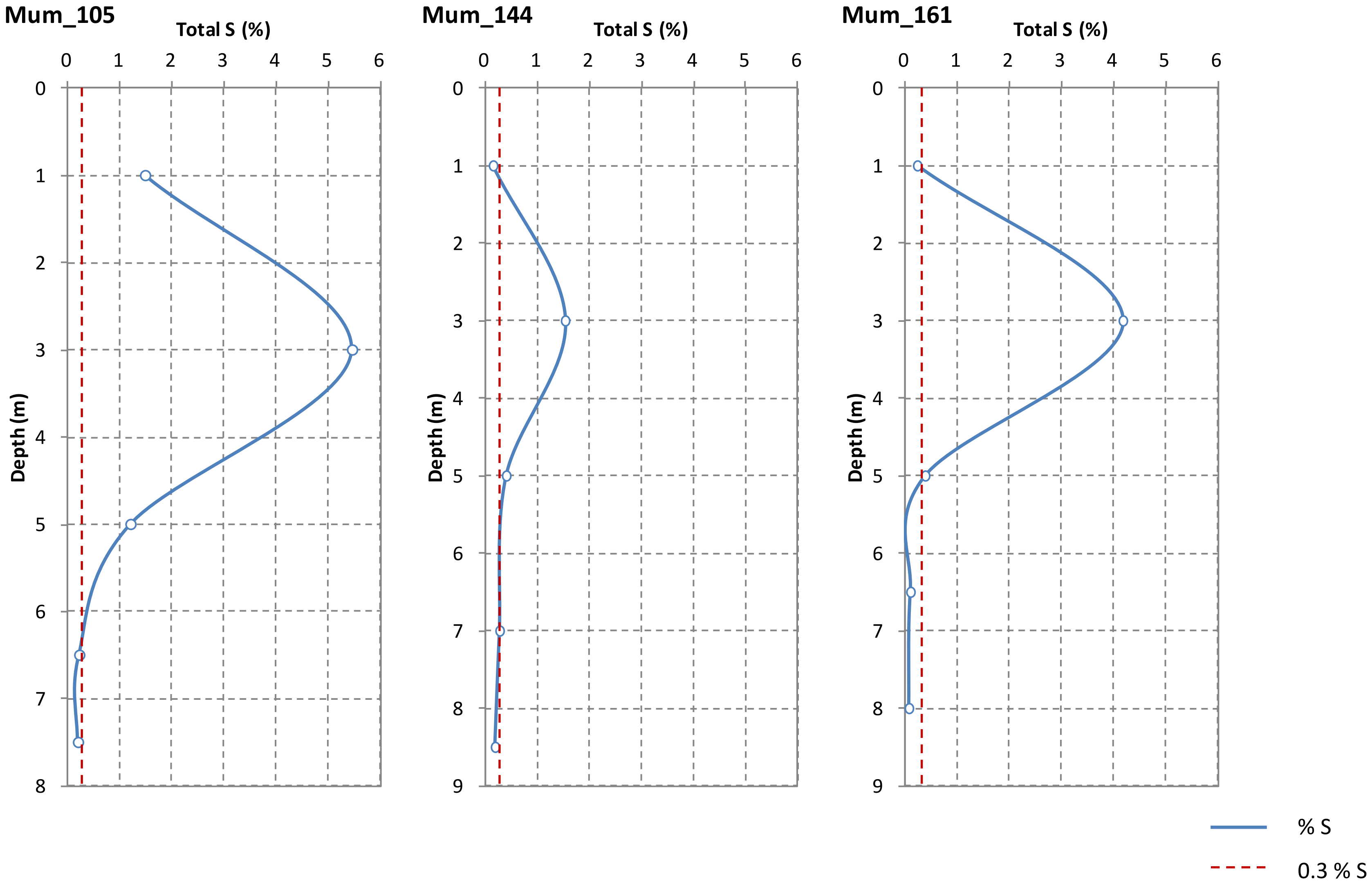


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| PN | PN0266 | | EnviroWorks Consulting<br>MUMMALOO DEPOSIT GEOCHEMICAL CHARACTERISATION<br>**% S CONTENT OF SELECTED DRILL HOLES CONT.** | **Figure 10** |
| Prep by | HC | 23/07/12 | | soilwater GROUP |
| Rev'd by | ASP | 23/07/12 | | |
| Revision No. | 0 | | | |

### 3.3 ACID NEUTRALISING CAPACITY (ANC)

The ANC of the 12 samples analysed in this investigation are provided in Table 3. The majority of the samples had negligible total buffering capacities, with ANC values < 10 kg $H_2SO_4$/t. The exceptions to this were samples from MUM_079/0-2, MUM_144/0-2 and MUM_013/0-2 which had ANC values of 167, 39.9 and 35.8 kg $H_2SO_4$/t respectively.

CarbNP is a measure of the readily available buffering capacity of the material and for all the samples the CarbNP was significantly lower than that for ANC. This suggests that the majority of the buffering species are composed of aluminosilicates minerals which are important for buffering at pH <4.0.

Table 3: Results of the detailed ARD analysis of the 12 selected samples

| Sample ID | MPA (kg $H_2SO_4$/t) | ANC (kg $H_2SO_4$/t) | CarbNP (kg $H_2SO_4$/t) | $NAPP_{MPA\text{-}CarbNP}$ (kg $H_2SO_4$/t) | $NAG_{pH}$ | $NAG_{pH4.5}$ (kg $H_2SO_4$/t) | $NAH_{pH7.0}$ (kg $H_2SO_4$/t) |
|---|---|---|---|---|---|---|---|
| MUM_077/0-2 | <0.153 | 3.3 | 0.196 | -0.043 | 6 | <0.1 | 18 |
| MUM_077/2-4 | 0.153 | 7 | 0.392 | -0.239 | 6.7 | <0.1 | 4.7 |
| MUM_077/4-6 | <0.153 | 0.5 | 0.196 | -0.043 | 5.2 | <0.1 | 20.8 |
| MUM_077/10-12 | 0.2142 | 0.5 | 0.196 | 0.0182 | 5.7 | <0.1 | 13.4 |
| MUM_077/14-16 | <0.153 | 0.5 | 0.196 | -0.043 | 5.9 | <0.1 | 17.4 |
| MUM_079/0-2 | <0.153 | 167 | 19.894 | -19.741 | 10.8 | <0.1 | <0.1 |
| MUM_079/2-4 | <0.153 | 4.9 | 0.392 | -0.239 | 6.8 | <0.1 | 0.4 |
| MUM_079/8-10 | <0.153 | 0.5 | 0.196 | -0.043 | 5.8 | <0.1 | 11.6 |
| MUM_144/0-2 | <0.153 | 39.9 | 5.586 | -5.433 | 9.8 | <0.1 | <0.1 |
| MUM_144/6-8 | 0.153 | 0.5 | 0.196 | -0.043 | 4.1 | 1.5 | 5.6 |
| MUM_144/8-9 | <0.153 | 0.5 | 0.196 | -0.043 | 4.6 | <0.1 | 6.9 |
| MUM_013/0-2 | <0.153 | 35.8 | 4.508 | -4.355 | 8 | <0.1 | <0.1 |

### 3.4 ACID BASE ACCOUNT (ABA)

The ABA for the 12 samples is presented in Table 3 and the ABA plot shown in Figure 11. The majority of the Maximum Potential Acidity (MPA) values determined using the chromium reducible sulfur ($S_{CR}$) results were found to be at or below the limit of detection (0.153). When these calculated MPA values are compared to the Net Acid Producing Potential ($NAPP_{SCR}$) the values range from -19.741 to -0.043 kg $H_2SO_4$/t.

The ABA results indentify that all the materials to be mined at the Mummaloo deposit are likely to be non-acid forming (NAF) due to the absence of any sulfides. Figure 12 shows the plot of $NAPP_{MPA\text{-}SCR}$ versus the $NAG_{pH}$.

### 3.5 NET ACID GENERATING (NAG) CAPACITY

The static NAG results for the 12 samples analysed are provided in Table 3. The $NAG_{pH}$ for all the samples ranged from 4.1 to 10.8 with a mean of 6.6. For the majority of the samples (except MUM_144/6-8) the $NAG_{pH}$ remained above 4.5, indicating that they are unlikely to generate excessive acidity that may have an adverse effect on the environment.

Several of the materials tested yielded alkaline $NAG_{pH}$ values (i.e. $NAG_{pH}$ >7). These materials generally exist in a naturally acidic condition, thus indicating that the alkalinity released during hydrogen peroxide oxidation is not readily available under typical leaching conditions.

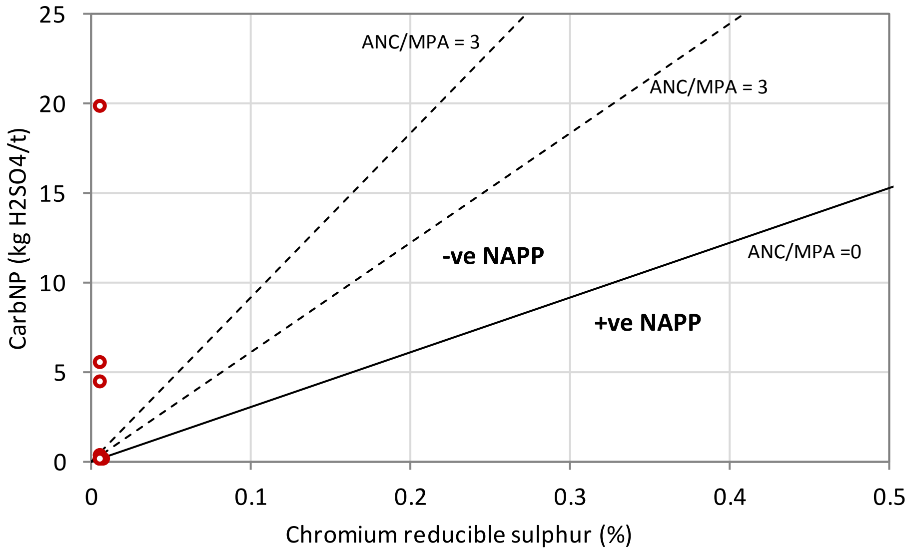


Figure 11: Acid-base account (ABA) plot

### 3.6 GEOCHEMICAL CLASSIFICATION

The geochemical classification of the 12 samples tested from the Mummaloo deposit are presented in Figure 12. None of the materials tested in this investigation are classified as Potential Acid Forming (PAF), due to the absence of any appreciable sulfide minerals. All the materials are classified as No-Acid Forming (NAF) with one sample classified as Uncertain (UC). Figure 12 shows the plot of $NAPP_{MPA-SCR}$ versus the $NAG_{pH}$. The majority of the samples fall at or close to 0 kg $H_2SO_4$/t. This is the result of there being no significant sulfide or buffering minerals in the material. The single UC classified material is not a concern as it shows that the materials tested are inert in nature (from a potential acid generation point of view) with no sulphidic materials present.

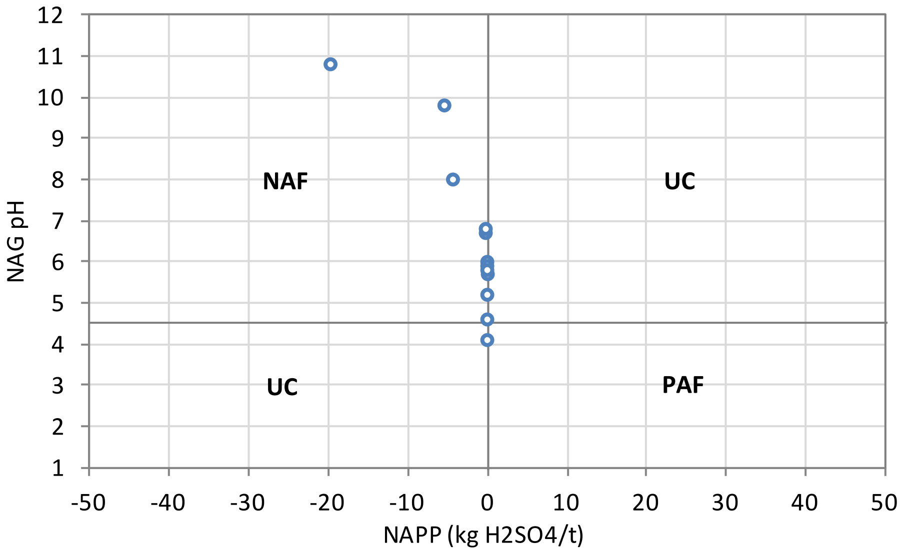


Figure 12: Geochemical classification plot for selected Mummaloo samples

### 3.7 MULTI-ELEMENT COMPOSITION

Element enrichment was determined using the Geochemical Abundance Index (GAI), through Equation 1:

$$GAI = \log_2\left(\frac{c}{1.5 * ACA}\right), \qquad \text{Eqn. 1}$$

with *c* = elements content of the sample (mg/kg) and *ACA* = crustal abundance (Bowen, 1979). A GAI of 0 indicates that the content of the element is less than, or similar to, the average crustal abundance. A GAI of 3 corresponds to a 12-fold enrichment above the average crustal abundance, and a GAI of 6 indicates a 96-fold or greater enrichment above the average crustal abundance. In general, a GAI >3 indicates significant enrichment.

Elemental compositions were compared against the Department of Environment and Conservation (DEC) Ecological Investigation Limits (EIL; DEC, 2010) to identify metals and metalloids that, if present, may pose a significant risk to the surrounding environment or to environmental values as a result of non-acid metalliferous drainage. The EIL used by the DEC are based primarily on the Environmental Investigation Levels listed in the Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites (ANZECC/NHMRC, 1992). They represent only screening levels, in which to provide a first-pass or a Tier 1 level of assessment for a site. It is important to note that these levels do not specifically apply to mineralised zones whereby elevated metal and metalloid contents often exceed the EIL criteria in a natural functioning ecosystem. Site specific information should therefore be used in conjunction with the EIL to assess the appropriateness of these criteria values. Therefore the values of the EIL are compared to the ACA values to provide a context with which to interpret them.

The multi-element composition of the 12 material samples is provided in Tables 4 and 5 and their corresponding enrichment compared to the average global crustal abundances, is provided in Tables 6 and 7. The results of the analysis found that for the majority of elements the elemental content of the materials was below the corresponding EIL. The exception to this was V in 5 of the samples where the content exceeded the EIL of 50 mg/kg. However, when compared against the average crustal abundance none of the samples are enriched with respect to V. No elements were found to be significantly enriched with respect to GAI (Tables 6 and 7).

As the elemental content of the materials does not exceed the EIL and the risk of ARD is low (negative NAPP) the risk of metalliferous drainage (MD) resulting from disturbance of these materials is also likely to be negligible.

Table 4: Multi-element composition of representative waste material samples from the Deception Deposit tested in this investigation. Values in bold exceed the DEC Ecological Investigation Levels (EIL; DEC, 2010).

| | Multi-element composition (mg/kg) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Al** | **B** | **Fe** | **As** | **Se** | **Ag** | **Ba** | **Cd** | **Bi** | **Co** | **Cr** | **U** |
| *EIL* | - | - | - | *20* | - | - | *300* | *3* | - | *50* | *400* | - |
| MUM_077/0-2 | 6480 | <50 | 40800 | 1.4 | <1 | <0.1 | 73.5 | <0.1 | <0.1 | 4.6 | 4.1 | 0.2 |
| MUM_077/2-4 | 12300 | <50 | 36000 | 1.7 | <1 | <0.1 | 5.7 | <0.1 | <0.1 | 6.2 | 10.6 | 1.4 |
| MUM_077/4-6 | 5860 | <50 | 42700 | 0.6 | <1 | <0.1 | 2.0 | <0.1 | <0.1 | 2.2 | 4.1 | 0.8 |
| MUM_077/10-12 | 5040 | <50 | 21900 | 0.4 | <1 | <0.1 | 41.1 | <0.1 | <0.1 | 1.8 | 3.8 | 0.3 |
| MUM_077/14-16 | 5040 | <50 | 21200 | 1.8 | <1 | <0.1 | 107 | <0.1 | <0.1 | 2.3 | 1.1 | 0.2 |
| MUM_079/0-2 | 7840 | <50 | 68200 | 5.0 | <1 | <0.1 | 162 | <0.1 | <0.1 | 6.2 | 27.1 | 3.5 |
| MUM_079/2-4 | 9550 | <50 | 128000 | 3.7 | <1 | <0.1 | 6.5 | <0.1 | <0.1 | 3.3 | 20.0 | 6.3 |
| MUM_079/8-10 | 6940 | <50 | 58000 | 2.0 | <1 | <0.1 | 26.3 | <0.1 | <0.1 | 1.1 | 4.2 | 0.5 |
| MUM_144/0-2 | 14200 | <50 | 58400 | 0.4 | <1 | <0.1 | 110 | <0.1 | <0.1 | 6.1 | 212 | 0.4 |
| MUM_144/6-8 | 9060 | <50 | 96700 | 0.1 | <1 | <0.1 | <0.1 | <0.1 | <0.1 | 1.3 | 115 | 0.1 |
| MUM_144/8-9 | 14100 | <50 | 84000 | <0.1 | <1 | <0.1 | 2.2 | <0.1 | <0.1 | 1.0 | 166 | <0.1 |
| MUM_013/0-2 | 7180 | <50 | 70000 | 0.2 | <1 | <0.1 | 111 | <0.1 | <0.1 | 4.4 | 187 | 0.5 |

Table 5: Multi-element composition of representative waste material samples from the Deception Deposit tested in this investigation. Values in bold exceed the DEC Ecological Investigation Levels (EIL; DEC, 2010).

| | Multi-element composition (mg/kg) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cu** | **Th** | **Mn** | **Sr** | **Mo** | **Ni** | **Pb** | **Sb** | **Zn** | **V** | **Sn** | **Hg** |
| *EIL* | *100* | *-* | *500* | *-* | *40* | *60* | *60* | *-* | *20* | *50* | *50* | *1* |
| MUM_077/0-2 | 15.8 | <0.1 | 8.7 | 14.5 | <0.1 | 0.9 | 9.2 | <0.1 | 2.7 | **93** | <0.1 | <0.1 |
| MUM_077/2-4 | 21.3 | <0.1 | 18.7 | 10.6 | <0.1 | 11.0 | 14.1 | <0.1 | 4.4 | **74** | <0.1 | <0.1 |
| MUM_077/4-6 | 17.6 | <0.1 | 17.0 | 3.7 | <0.1 | 1.2 | 40.8 | <0.1 | 1.9 | **111** | <0.1 | <0.1 |
| MUM_077/10-12 | 13.8 | <0.1 | 13.6 | 2.7 | <0.1 | 1.0 | 7.7 | <0.1 | 1.7 | **55** | <0.1 | <0.1 |
| MUM_077/14-16 | 11.7 | <0.1 | 29.6 | 4.6 | <0.1 | 0.7 | 16.8 | <0.1 | 5.6 | 47 | <0.1 | <0.1 |
| MUM_079/0-2 | 11.7 | 4.8 | 66.6 | 182 | <0.1 | 12.0 | 6.7 | <0.1 | <0.1 | 37 | <0.1 | <0.1 |
| MUM_079/2-4 | 8.0 | 7.4 | 48.8 | 35.7 | <0.1 | 2.9 | 4.0 | <0.1 | <0.1 | 36 | <0.1 | <0.1 |
| MUM_079/8-10 | 3.2 | <0.1 | 0.7 | 4.1 | <0.1 | <0.1 | 1.0 | <0.1 | <0.1 | 20 | <0.1 | <0.1 |
| MUM_144/0-2 | 24.4 | 2.2 | 62.7 | 72.0 | <0.1 | 41.0 | 6.8 | <0.1 | 1.5 | 32 | <0.1 | <0.1 |
| MUM_144/6-8 | 27.8 | <0.1 | 0.5 | 0.6 | <0.1 | 6.2 | 2.1 | <0.1 | <0.1 | 13 | <0.1 | <0.1 |
| MUM_144/8-9 | 17.8 | <0.1 | 0.3 | 1.3 | <0.1 | 7.3 | 2.2 | <0.1 | <0.1 | 12 | <0.1 | <0.1 |
| MUM_013/0-2 | 12.8 | <0.1 | 31.3 | 63.1 | <0.1 | 17.1 | 3.3 | <0.1 | <0.1 | **61** | <0.1 | <0.1 |

Table 6: Global abundance Index (GAI) for the various metals and metalloids tested in this investigation. Values in bold represent significant enrichment compared to the average crustal abundance (ACA). For metal contents less than detection, a value of 0.5 times the detection limit was used to calculate the GAI.

| | ACA (mg/kg) and GAI | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Al** | **B** | **Fe** | **As** | **Se** | **Ag** | **Ba** | **Cd** | **Bi** | **Co** | **Cr** | **U** |
| | *82000* | *10* | *41000* | *1.5* | *0.05* | *0.07* | *500* | *0.11* | *0.048* | *20* | *100* | *2.4* |
| MUM_077/0-2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_077/2-4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_077/4-6 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_077/10-12 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_077/14-16 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_079/0-2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_079/2-4 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| MUM_079/8-10 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_144/0-2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_144/6-8 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_144/8-9 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_013/0-2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 7: Global abundance Index (GAI) for the various metals and metalloids tested in this investigation. Values in bold represent significant enrichment compared to the average crustal abundance (ACA). For metal contents less than detection, a value of 0.5 times the detection limit was used to calculate the GAI.

| | ACA (mg/kg) and GAI | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cu** | **Th** | **Mn** | **Sr** | **Mo** | **Ni** | **Pb** | **Sb** | **Zn** | **V** | **Sn** | **Hg** |
| | *50* | *12* | *950* | *370* | *1.5* | *80* | *14* | *0.2* | *75* | *160* | *2.2* | *0.05* |
| MUM_077/0-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_077/2-4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_077/4-6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| MUM_077/10-12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_077/14-16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_079/0-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_079/2-4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_079/8-10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_144/0-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_144/6-8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_144/8-9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MUM_013/0-2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## 4. MANAGEMENT OF PAF

The above assessment of the materials from the Mummaloo deposit found that there was no low risk of PAF material and negligible risk of metalliferous drainage. As such there are no requirement for management of PAF at the proposed Mummaloo site.

## 5. CONCLUSIONS & RECOMMENDATIONS

A geochemical characterisation was undertaken for the proposed Mummaloo deposit to assess the potential for Acid Rock (ARD) and Metalliferous (MD) drainage following disturbance of these materials, and to identify the distribution of any other potential problematic waste rock characteristics, which if present, may have the potential to impact on the success of rehabilitation. The major findings from this investigation are:

- A desktop study of the assay data from 191 drill holes sampled in the deposit found that the majority of the material in the deposit had total % S contents below the DEC 0.3 % criteria. Of those that were >0.3 %, all were found in the top 6 m of the profiles and as such are unlikely to contain sulphidic material due to the highly weathered nature of the material. Corresponding chromium reducible sulfur contents of samples analysed for detailed ARD found that the majority of the S in the material was $SO_4$-S which does not contribute the ARD.

- Acid Base Accounting (ABA) and geochemical characterisation of 12 selected sample from across the deposit identified the materials as non-acid forming (NAF) and as a result no specific management strategy for handling of PAF is required.

- The majority of the waste material contains low levels of metals and metalloids with only V being found to exceed the EIL. However, when compared the average crustal abundance none of the samples are enriched with respect to V. No elements were found to be significantly enriched with respect to GAI. Any low level release of metals or metalloids, which may occur, are likely to be rapidly adsorbed by the aquifer materials; hence there is a low risk for metalliferous drainage to occur once materials are excavated, and no specific management of MD material is required.

- As a result of the findings no PAF materials were identify in the Mummaloo deposit and as a result there no specific ARD management strategies for the material to be mined is required.

## 6. REFERENCES

AMIRA (2002). ARD Test Handbook. Project 387A: Prediction and Kinetic Control of Acid Mine Drainage, AMIRA International, Melbourne, Australia.

Bowen, H.J.M. (1979). *The Elemental Geochemistry of Rocks*, Academic Press, London.

DEC (2009). *Identification and Investigation of Acid Sulfate Soils and Acidic Landscapes*, Acid Sulfate Soils Guideline Series, Department of Environment and Conservation. Perth, Western Australia.

DEC (2010). *Assessment Levels for Soil, Sediment and Water*, Contaminated Sites Management Series, Department of Environment and Conservation (DEC), Perth, Western Australia.

Price, W.A. (2009). *Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials*. MEND Report 1.20.1. CANMET Mining and Mineral Sciences Laboratories, Smithers, British Columbia